Research Notes

Program Steering Committee (PSC): Geotechnical/Structures

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Title: Generation-2 Bridge Fragility Relationships, Phase 2

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Product Category: (6) New/improved models for decision support tool

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TITLE:
Generation-2 Bridge Fragility Relationships, Phase 2

Development of Production Models for Concrete Bridges.

WHAT IS THE NEED?

Major earthquakes can severely disrupt transportation networks. Immediately after an earthquake, Caltrans emergency managers and decision-makers need to understand field conditions to coordinate the response and to dispatch bridge inspection resources. Since 2008, Caltrans has used the ShakeCast alerting system to provide early situational awareness to emergency managers. ShakeCast uses a combination of ground-shaking maps developed in near-real time by the United States Geological Survey, coupled with pre-calculated bridge fragility relationships, to rapidly estimate the bridge damage. Fragility relationships are statistical models describing the probability that a specific level of shaking will induce varying degrees of bridge damage, ranging from minor spalling of concrete to complete bridge collapse.

The first-generation fragility models, developed in the early 1990s, have several limitations that affect their usefulness for emergency response and planning applications. Most importantly, the models do not address substantial variations in bridge performance associated with the full range of bridge types, configurations, and design eras existing in California. In addition, the bridge damage-state definitions are not clearly associated with the identification of post-earthquake emergency repair needs and available traffic capacity, and they provide only a qualitative sense of damage for the entire bridge, with minimal details about quantitative engineering metrics or where the damage might be located.

Task 1780 is the second phase of Project P266 that builds upon the knowledge and experience gained through an initial end-to-end application of the methodology completed

under the phase-one feasibility studies (Task 1755). This new phase will develop and optimize a set of generation-2 fragility models for most concrete bridge classes in California.

WHAT ARE WE DOING?

Task 1780 involves a combination of closely-coordinated internal and contract research. The internal work is focused on characterizing California's bridge inventory while the contract work is conducting an extensive program of analytical modeling.

Internal work on bridge-inventory characterization involves development of a new bridge taxonomy to group bridge classes/subclasses according to salient design features relevant to seismic performance. Data from a variety of Departmental information assets are being synthesized to first characterize the range of existing idealized bridge classes, and then to assign individual bridges to a class, thus enabling assignment of fragility models for ShakeCast. Additionally, the capacity of various bridge-component details is being characterized as a set of component capacity limit state (CCLS) models. These models characterize component damage as a function of earthquake demands, and are being developed in consultation with Caltrans' bridge design and maintenance experts.

Analytical modeling work is being completed under contract with the Georgia Institute of Technology. For each idealized bridge class/subclass, representative analytical bridge models are established using ranges of design details compiled through review of applicable bridge plans. Probabilistic seismic demand models (PSDM's) are then developed though a stochastic application of a non-linear finite-element modeling procedure. For each bridge type, a set of up to several hundred simulations are performed using a wide range of earthquake motions and in-class permutations of the representative bridge model. Overall, hundreds of thousands of individual simulations will be performed to address all bridge classes. Once the PSDM's are established, they are combined with applicable capacity (CCLS) models provided by Caltrans to yield component fragility models which characterize component-level damage. The component models are then combined according to the details of a specific bridge type to yield a bridge-system fragility model which is used to characterize operational consequences of bridge damage. The system-level models serve as the primary basis for ShakeCast alerting.

The overall work plan involves a sequence of activities designed to systematically consider the full range of concrete bridge classes. After completing initial sensitivity studies meant to refine the taxonomy, base fragility models and adjustment factors will be developed and optimized. The production analytical work will first consider box-girder systems that are common in California.

WHAT IS OUR GOAL?

The goal of Project P266 is to develop a new generation of more accurate and more useful bridge fragility models for incorporation into Caltrans' ShakeCast earthquake alerting system and to support seismic reliability evaluations of the state bridge inventory. Task 1780 will complete generation-2 models for most concrete bridge types, representing nearly 80% of California's bridge inventory.

WHAT IS THE BENEFIT?

Successful development and deployment of improved fragility models into ShakeCast will facilitate a more effective post-earthquake emergency response where incident commanders, decision makers, and field inspectors have excellent situational awareness early in the response-operations timeline. Additionally, these same tools will improve planning capabilities by providing a uniform basis to assess the seismic reliability of California's bridge inventory over a full range of hazard levels. Together, the improved fragility models within ShakeCast will provide for faster post-earthquake emergency response and restoration of network mobility. It will also support planning decisions into the most effective allocations of capital resources for improved seismic safety and a more reliable transportation network.

WHAT IS THE PROGRESS TO DATE?

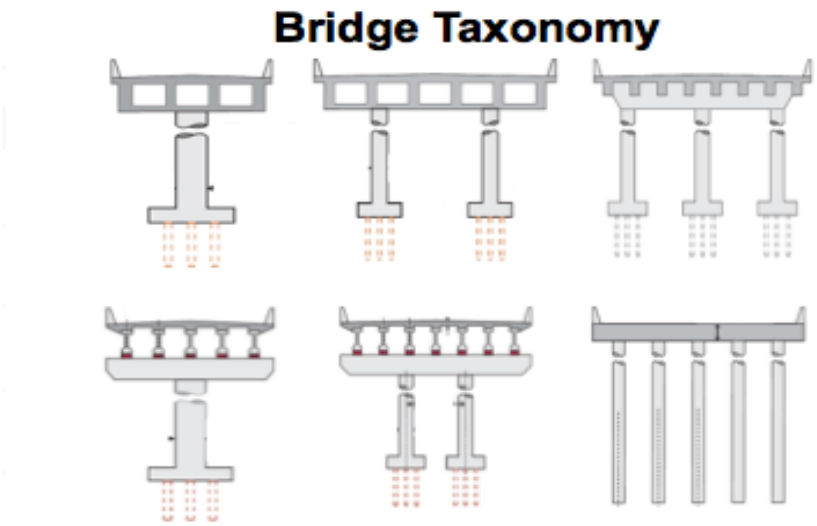
Task 1780 got underway in August 2013, and is nearing completion of initial inventory-characterization work and analytical sensitivity studies. The goal of both activities is to optimize the generation-2 taxonomy and to identify an efficient work strategy to complete the production analyses so as to yield a manageable number of fragility models that both reflect the California bridge inventory and capture distinct seismic performance differences. The initial focus is on box-girder bridges.

The internal inventory-characterization effort has centered on development of algorithms to synthesize data from various existing information assets for purposes of assigning idealized bridge-class codes using the emerging generation-2 taxonomy. The breadth of the taxonomy for purposes of demand modeling has stabilized at about fifteen parameters, each having multiple values. These capture key design differences between bridge types such as code design era and retrofit, span range and bridge system, abutment and interior support types, skew, design ground motion, and geometric variations such as bridge height and frame balance. Rule-based methods, those not requiring individual bridge-plan reviews, have been established to assign eleven of the parameters to most bridges with varying degrees of confidence. These codes could be assigned to approximately half of the box-girder inventory with high confidence and were used to identify several hundred idealized bridge classes. The sixty nine idealized classes which include at least ten bridges will serve as the starting point for analytical modeling.

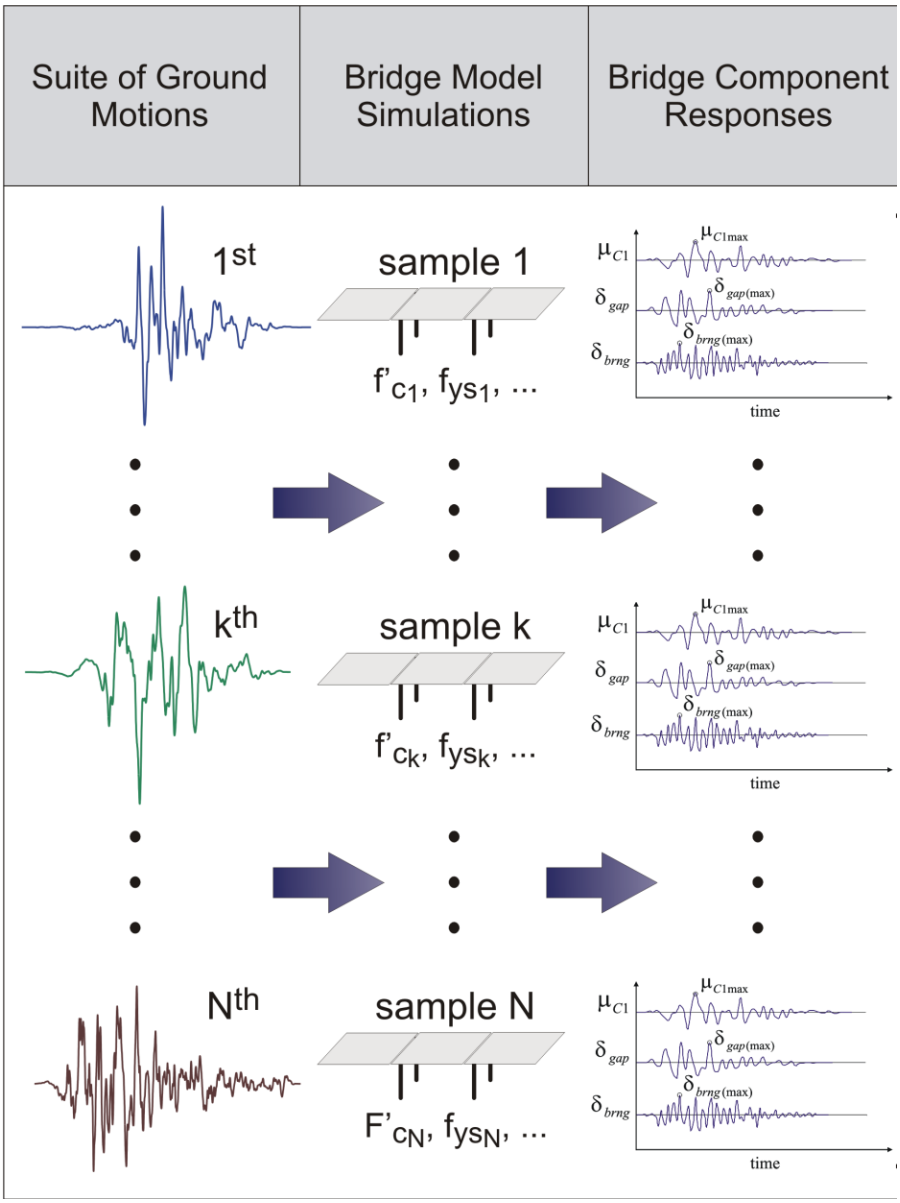
The analytical sensitivity-study effort has explored whether the performance of alternative taxonomy-code combinations could be considered as equivalent systems for purposes of demand modeling. For example, it was shown that multi-column bridges from different design eras will produce essentially the same demand model, though different capacity models will apply to each. Such ‘grouping’ of idealized systems into a fewer number of representative systems will allow substantial compression of the number of simulations that need to be performed, thus yielding a manageable production-analysis work plan.

Production analytical demand modeling of representative concrete box-girder bridge systems is expected to begin by the fall of 2014.

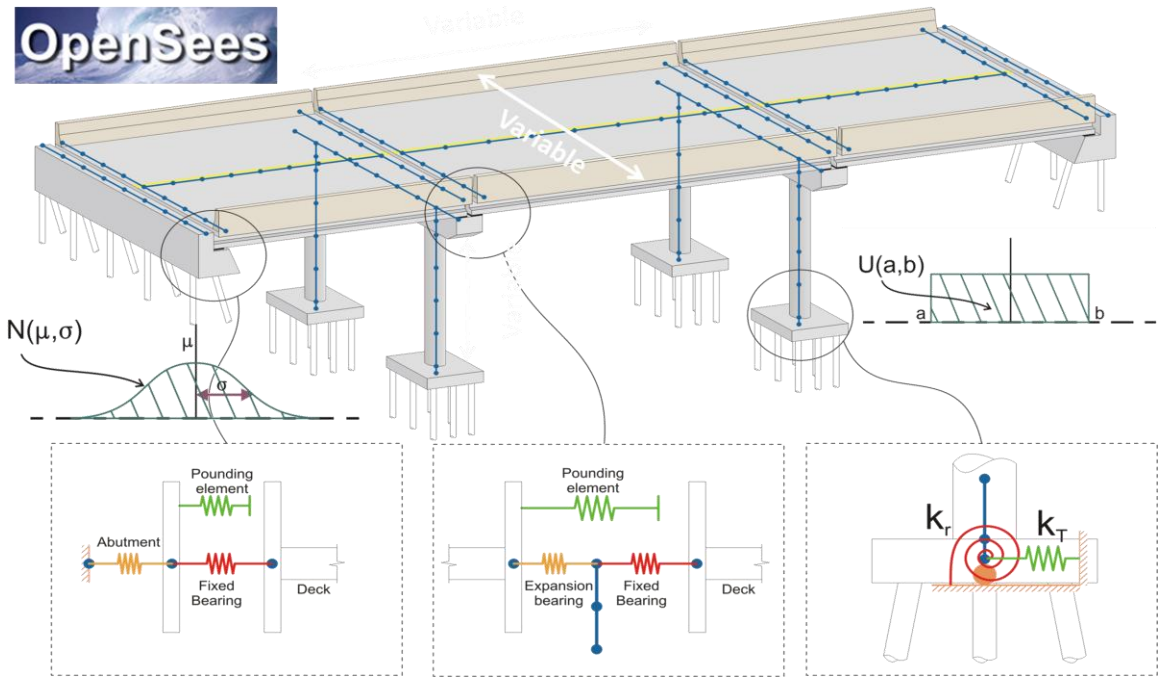
IMAGES



Current fragility models view these bridges and others as essentially the same type—a continuous concrete structure. The new taxonomy considers them separate classes, each having distinct seismic performance.



Stochastic method: Each bridge class and subclass is analyzed using multiple simulations to establish seismic performance over a wide range of earthquakes and bridge-class details.



Each simulation is performed using nonlinear, time-domain, finite-element analysis.